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Mission critical systems are typically large, have high performance, high reliability and stringent deadline requirements. Design methodology that separates functional design from the performance reliability and real-time requirements are no longer acceptable. The methodology should integrate functional correctness specification with the specification of performance, reliability, safety, security and real-time requirements. The approaches for the integrated specification of both the functional and nonfunctional aspects of systems design need to be investigated. Automated translation of the performance and reliability aspects of the design specification into an underlying modeling language need to be researched. Methods of trade-off and optimization between various competing measures of system effectiveness need to be developed. The objective is to investigate those issues, of integrated methods of system design specification, specification and solution of system performance and reliability modes.

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PROGRESS REPORT

Principal Investigator: Kishor Trivedi
PI Institution: Duke University
PI Phone Number: (919) 660-5269
Contract Title: Methodology for the Specification of Fault-Tolerant Real-Time Systems
Contract Number: ONR Grant N00014-91-J-4162
Reporting Period: 1 Oct 91 - 30 sep 92

1   Measures of Productivity

Under the auspices of this grant, we have published one journal article and three journal articles are accepted for publication. We have published one conference article and another will appear in 1993. We have written two book chapters (both invited). Both the books are expected to be published soon. A report on "Tools and Techniques for Dependability Modeling and Analysis: A Survey" was delivered to NSWC as requested by them [8].

The PI has been elected to be a Fellow of the IEEE. He was the program chair of the Eleventh Symposium on Reliable Distributed Systems and he guest-edited a special issue of the IEEE Transactions on Parallel and Distributed Systems (to appear in November 1992). The PI on the editorial boards of the Journal of Electronic Testing (JETTA) and the Journal of Computer System Science and Engineering. He is designated the Chairman of the 1993 IASTED Conference The PI is a voting member of the IEEE Computer Society Publications Board and he chairs the Transactions Operations Committee of the Society. He was on the program and organizing committees of many conferences. He was invited as a tutorial speaker at SIGMETRICS 92 and was an invited speaker at the Numerical Linear Algebra: Markov Chains and Queueing Networks Workshop in Minneapolis, Jan. 92.

Tools, SPNP and SHARPE, that we have developed earlier, are in wide circulation and use.

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2   Detailed Summary of Technical Progress

Under this grant we have made considerable progress. First, an invited paper containing formal definition of stochastic reward nets (SRNs), their logical, temporal and sensitivity analysis are discussed in [3].

Several interesting applications of SRNs have been developed. This includes analyzing concurrent and fault-tolerant software [4], performance models of client-server systems [5], a performance model of a polling system [2], and a performability model of real-time system [9]. In [5] we have collaborated with a researcher from the GTE Labs in Waltham, MA.

Many of the application papers necessitated the use of approximate models in order to avoid largeness. In [5] SRN folding has been used. In [9] behavioral decomposition has been used while in [2] fixed-point iteration has been used. In each case, the approximation error is studied empirically. In [2] existence of the fixed point solution is shown using Brouwer's fixed-point theorem.

We have analyzed the reliability of FDDI token ring using combinatorial methods [6]. We have also analyzed the reliability of disk arrays [7]. Finally, a very detailed model of program completion time on processor subject to failure and repair has been developed and solved using transform inversion techniques [1].

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3 Lists of Publications, Presentations and Reports

References

[1] P. F. Chimento, Jr. and K. S. Trivedi, Completion Time of Programs on Processors Subject to Failure and Repair. *IEEE Transactions on Computers*, to appear.

[2] H. Choi and K. S. Trivedi. Approximate Performance Models of Polling Systems using Stochastic Petri Nets. In *Proceedings of the IEEE INFOCOM 92*, Florence, Italy, May 1992.

[3] G. Ciardo, A. Blakemore, P.F. Chimento, Jr., J.K. Muppala, and K.S. Trivedi, "Automated Generation and Analysis of Markov Reward Models using Stochastic Reward Nets," in *Linear Algebra, Markov Chains and Queuing Models*, Carl Meyer and Robert Plemmons (eds.), Springer-Verlag, to appear.

[4] G. Ciardo, J. Muppala, and K. S. Trivedi. Analyzing concurrent and fault-tolerant software using stochastic Petri nets. *Journal of Parallel and Distributed Computing*. Vol. 15, pp. 255-269, 1992.

[5] O. C. Ibe, H. Choi, and K. S. Trivedi. Performance Evaluation of Client-Server Systems. *IEEE Transactions on Parallel and Distributed Systems*. to appear.

[6] D. Logothetis and K. Trivedi, "Reliability Analysis of Various Station Attachment Schemes in a FDDI Token Ring," *In Proc. INFOCOM 93*, San Francisco, CA, March 1993.

[7] M. Malhotra and K. Trivedi, "Reliability Analysis of Redundant Arrays of Inexpensive Disks," *Journal of Parallel and Distributed Computing*, 1993.

[8] M. Malhotra, C. Wang and K. Trivedi "Tools and Techniques for Dependability Modeling and Analysis: A Survey" Tech Report, 1992.

[9] J.K. Muppala, S.P. Woolet, and K.S. Trivedi "On Modeling Performance of Real-Time Systems in the Presence of Failures," in: *Readings in Real-Time Systems*, Y.-H. Lee and C. M. Krishna (eds.), IEEE Press, 1992.

4   Transitions and DOD Interactions

We have had extensive discussions with Paul Wallenberger, Steve Howell, and Charles Yeh of NSWC. We have also had many discussions with Tom Lawrence of RADC. Bob Goettge and his company are likely to integrate our SHARPE tool with their START/1 tool. Our concurrent grant from NSF leverages the ONR grant very well.

Our two industrial contracts with Union Switch and Signals and Boeing are both involved with integrating dependability modeling in process of design. Once again, this is related to the ONR grant.

Our tools have elicited a lot of interest in universities as well as industry. For instance, we are currently designing and implementing and an intergrated toolkit for reliability analysis. Our tool SHARPE, HARP and SPNP are in the toolkit. We are helping Union Switch design a designer tool, D_RAMP, that contains SPNP as an engine. They have produced a graphical user interface for SPNP. Technical University of Vienna has integrated SHARPE in their real-time system design tool called MARPLE. University of Edinburgh and RPI have both produced a graphical user interface for SPNP.

We will be very interested in discussions with the TIGER (reliabilty modeling system) group at Navy about integrating TIGER with SHARPE; we believe this will be highly beneficial.

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5   Software and Hardware Prototypes

None.